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Short Communication

# Erosive wear properties of unidirectional carbon fiber reinforced PEEK composites

Xianqiang Pei [a,*], Klaus Friedrich [a,b]

[a] Institute for Composite Materials (IVW GmbH), Technical University of Kaiserslautern, 67663 Kaiserslautern, Germany
[b] CEREM, College of Engineering, King Saud University, Riyadh, Saudi Arabia

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ABSTRACT

The erosive wear properties of unidirectional carbon fiber (CF) reinforced polyetheretherketone (PEEK) composites were studied. A semi-ductile erosive wear manner was found regardless of the CF orientation. Wear mechanism analysis revealed that both cutting and deformation mechanisms existed in the erosion of the composites, although different damaging forms were involved depending on the impingement angles and CF orientation. To give further support on the erosion mechanisms, a special procedure was designed to observe the cross-sectional surface of the eroded composites, and the surface temperature variation was registered. It increased with increasing impingement angle, indicating higher energy dissipation by deformation, which is consistent with the revealed shift of the main erosive wear mechanism from cutting to deformation and ‘‘wholesale’’ fiber fracture.



## 1. Introduction

Erosive wear by solid particles is a typical wear mode, in which solid particles are entrained by gas or fluids and impinge on the surface of a target, resulting in a loss of material. At the beginning of investigations on erosive wear, much attention was paid to metals. Several advantages of polymeric materials over metals, however, have resulted in the use of polymeric materials in many industrial applications in which abrasive particles are critical issues, which trigger the urgency of erosive wear studies on polymer based (composite) materials [1–3].

Nowadays, fiber reinforced polymer composites are often used as load bearing elements of abrasion or erosion subjected structures. To help the development of erosion resistant polymeric composites, it is important to study the erosive wear behavior of fiber reinforced polymer composites from a basic point of view. Among the widely used polymeric materials, PEEK has found more and more application as tribomaterial due to its good tribological performance and high strength. As for the erosive wear behavior of PEEK composites, some work has been done up to now. To get higher energy by single impact, steel balls were used by Tewari et al. [4] in the erosion study of PEEK composites. It is also found that the fiber orientation has a significant influence on the erosion behavior of PEEK composites at lower impact angles [5]. Regarding the erosion mode of PEEK composites, a shift from ductile to semi-ductile behavior is found when brittle fibers (CFs, GFs, etc.) were incorporated into PEEK matrix [6,7].

Even the above progress, the erosive wear mechanism of PEEK composites has to be analyzed in-depth by further characterization of the eroded surfaces. In this communication, the temperature of the eroded PEEK composites' surface were registered immediately after the erosion tests, and special procedure was designed and used to characterize the cross-sectional surface morphology of the eroded composites. It is expected to give more support on the erosion mechanism of PEEK composites put forward by traditional SEM observation.

## 2. Experimental

### 2.1. Materials

The material investigated in this study is a Fiberite XC-2 unidirectional CF/PEEK system (ICI's Fiberite Division in Tempe, Arizona, USA), consisting of 60 vol% AS4 carbon fibers in a thermoplastic polyetheretherketone (PEEK) matrix. It has been found that the incorporation of the unidirectional CF greatly improved the wear resistance of the PEEK matrix [8]. Square type specimens with a size of 25 mm × 25 mm were cut from the as received composite plates (thickness 4.5 mm) and used for the erosive wear tests.

* Corresponding author. Tel.: +49 631 2017243; fax: +49 631 2017196.
*E-mail address:* xianqiang.pei@googlemail.com (X. Pei).

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### 2.2. Erosive wear tests

The erosive wear tests were conducted on a sand-blasting type facility, on which the erodent particles are driven and accelerated by compressed air. The length and diameter of the nozzle are 80 mm and 10 mm, respectively.

The erodent particles used in the present study are angular steel grits with an average size of 200–500 μm, as shown in Fig. 1. The velocity of the particles was determined to be about 25 m/s using the double disk method [9]. All the samples were eroded in an erosive wear chamber at room temperature, in which a fixed area of 20 mm in diameter was exposed to the erodents for a period of 180 s. The mass flow rate of the particles impinged on the exposed surface was determined to be 12.4 g/s at normal impact. The mass loss of the samples after erosion was measured and used to calculate the erosion rate. The temperature of the sample surfaces was determined before and after erosion by using an infrared thermometer (Testo Quicktemp 850-2).

To reveal the effects of CFs orientation on the erosive wear behavior of the composites, composite plates with perpendicular, parallel and 45° tilted CF orientation (Fig. 2) were tested. The impingement angle is referred to as the angle between the nozzle and the sample surface. It was varied 15° stepwise from 15° to 90°. In the present study, at least three repetitive tests were performed for calculating the mean erosion rate. The values of the error bars were got by calculating the standard deviation of at least three repeated wear results. The worn surfaces of the composite plates were observed by using a scanning electron microscope (SEM, JSM-6300, Tokyo, Japan). To observe the damages in the sub-surfaces, samples with different CFs orientation were cut into two parts along the dotted line in Fig. 2. After polishing the cut surfaces finely, the two halfs were again put together and used as a test sample. After erosion, the parts were separated, and the cross-sectional surfaces (after additional gold coating) could be observed in the SEM.

## 3. Results and discussion

The erosive wear rate of the unidirectional CF reinforced PEEK composites are shown in Fig. 3 as a function of the impingement angle. On the one hand, the erosion rate of the composites varied with increasing impingement angle. The maximum erosion rate took place at an impingement angle of around 45° to 60°, which indicated a mixed ductile/brittle erosive wear behavior of the PEEK composites studied [10]. As for the PEEK matrix, ductile erosion mode dominates the erosive wear process as indicated by the results of Arjula et al. [6], which shifts to semi-ductile erosion mode when fibers (CFs, GFs, etc.) are incorporated into the PEEK matrix [7,11,12]. Meanwhile, a semi-ductile erosion mode has also been found for other polymer based composites [13–15]. On the other hand, the CF orientation exerted some influence on the erosive wear resistance of the composites, among which better

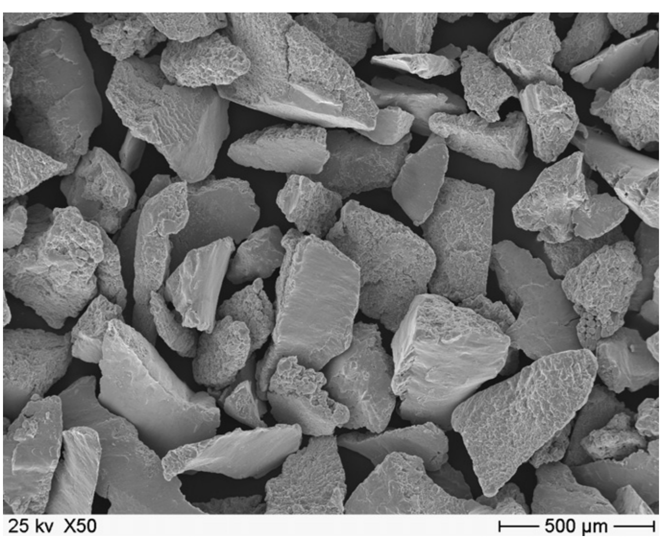


**Fig. 1.** SEM morphology of the steel grits.

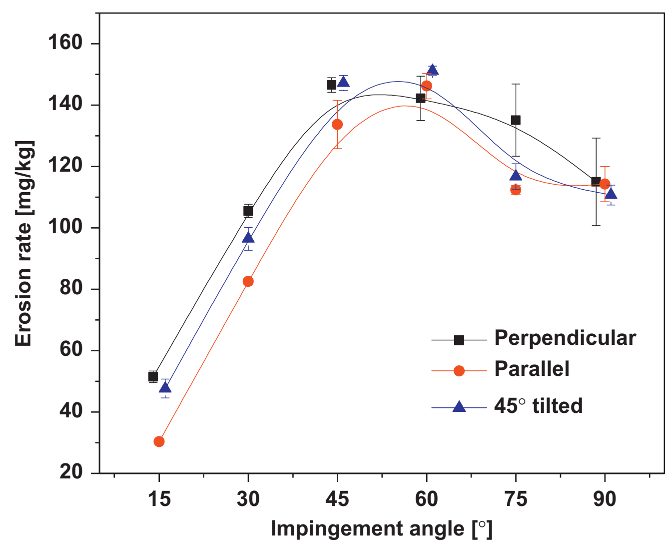


**Fig. 3.** Effects of impingement angle on the erosion rate of the unidirectional CF/PEEK composites.

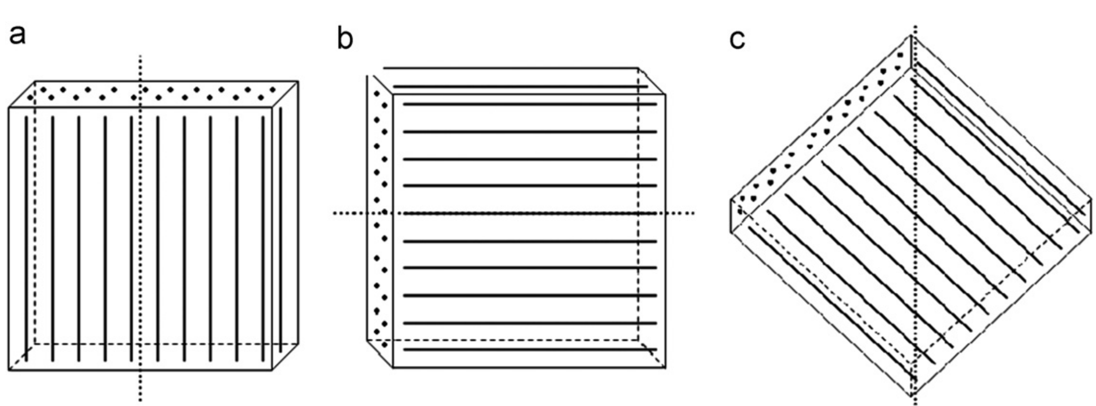


**Fig. 2.** Schematic diagram of the composite plates with different CFs orientation in the erosive wear tests: (a) perpendicular, (b) parallel, and (c) 45° tilted.